BALL—Bringing Advanced eLectricity to Life

Fuel Cells Newsletter

Issue 1 1Q 2000

Introducing ...

Ball introduces its Fuel Cells Newsletter. In this first issue, you will find information on:

- The portable power systems that Ball has developed
- Ball's involvement with fuel cells
- Our new website
- The fuel cell portable power systems (PPS) demonstrations held in conjunction with the Marines
- Common questions about the 50 W Ball PPS and hydrogen
- Upcoming events

The purpose of this portable power system newsletter is to keep customers, partners, suppliers and sponsors up to date on new product introductions and activities at Ball. This newsletter is also a forum for customers to provide Ball with feedback that they would like to share with the entire distribution. Ball is beginning a new era in turning its fuel cells into a product and the best way to launch this product is by communicating with our customers. ◇

Ball Demonstrates with the Marines

Ball Aerospace & Technologies Corp. is committed to serving customers and responding to specialized needs and requirements. This includes onsite and field demonstrations of our fuel cell power systems. Ball has been developing fuel cell power systems since 1992 and has evolved the initial product from a larger system to a small, compact and robust system. Ball has chosen to focus its efforts on low-power requirements where energy density, mobility, portability, ease of use, robustness and reliability are of major concern. Therefore, Ball is focused on supplying power in the range from 5 W to 500 W for military and commercial applications.

In a DARPA[1] sponsored activity, Ball supported the 1st Marines S-6/I-MEF during 1999 through three field demonstrations, including a test exercise and two Combined Arms Exercises (CAX) at Twentynine Palms, California. The test exercise was a retransmission site test in preparation for CAX1 and CAX2. The fuel cell team was comprised of a member from Army CECOM[2], Kris Gardner, and two members from Ball Aerospace, Rich Reinker and Tim Quakenbush. This team supported the exercises and provided the hardware, setup and training for the Marines on the fuel cell systems. The team worked jointly with Maj. Dudley Griggs, Ssgt. Adrian Muzzall, Cpl. Shane Clark and Cpl. Garcia of the 1st Marines S-6 to set up the retransmission site using five retransmission nets on Bearmat Hill. Cpl. Clark and Cpl. Garcia assembled and operated all parts of the system with direction from members of the fuel cell team.

The fuel cells and all equipment were mounted in a Humvee[3] for transport to the retransmission site location. CECOM supplied their PPS-100 fuel cell system and DARPA/ARO[4] supplied two PPS-50 fuel cell systems for use. The PPS-100 can provide 100 W of power nominally with a peak power of about 130 W. This fuel cell is lightweight and rugged, weighing only 8.3 lb without the fuel source (add an additional 4 lb for the tank and 1 lb for the valving and fuel line). The PPS-50 systems are nominal 50 W power systems capable of up to 65 W of peak power. They too are compact and lightweight, weighing only 6.5 lb without the fuel source.

PPS-100 (100-watt portable power fuel cell system)

PPS-50 (50-watt portable power fuel cell system)

In addition, Ball arranged delivery of the hydrogen fuel source standard k bottles that were used at Twentynine Palms. Ball's custom hydrogen manifold fuel delivery and electrical control system was used to connect and operate the fuel sources. The power distribution system supplied 12 V to each of the radios and allowed for uninterruptable operation by automatically switching to the second hydrogen bottle when the first became empty. Maj. Griggs stated that after seeing two field demonstrations, he was comfortable with helo-lifting a fuel cell powered retransmission site without a backup generator.

[1] Defense Advanced Research Projects Agency
[2] Communications and Electronics Command – sponsor of the PPS-100
[3] High-mobility multi-purpose wheeled vehicle, used by military.
[4] Army Research Office

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The first field test demonstrated to the Marine Corps. that small fuel cells are a reliable, lightweight and cost-effective means of providing power for military applications. The fuel cells performed extremely well during the retransmission site test, operating for over 25 continuous hours.

Fuel cell power supplies strapped to a frame with the fuel supply tubing and power distribution connectors. The pair of PPS-50 supplies is left and center and the PPS-100 is on the right. The fuel supply flex hose enters the photograph from the upper left, and the potable water exhaust tubing exits at the lower left.

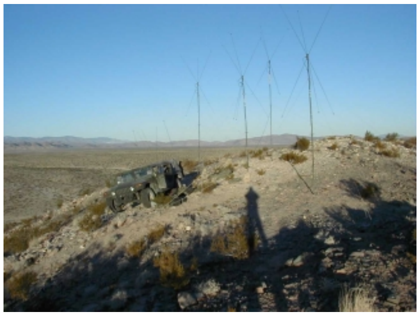
The fuel cell power systems inside of the Humvee with Cpl. Clark

Ball also supported CAX 1-00 and CAX 2-00 held in October and November respectively. The setup for the two exercises remained virtually unchanged from the test exercise configuration.

During the first CAX activity, the fuel cells were required for two different applications. The first application was to power a retransmission site at a location where any system problems could be mitigated. The Marines chose a site to support communications in the Quackenbush corridor that was accessible with a Humvee. The second application during CAX1 was structured to fully load all three fuel cell systems. Both events were operated from the Humvee.

The fuel cell systems powered nine PRC-119 radios (system capacity is 12 radios simultaneously) and a laptop computer from 18 Oct through 19 Oct for 20 hours with no glitches in power. One PPS-50 was loaded with the two busiest nets (four radios) to test heavy communications traffic conditions. The remaining five radios were attached to the PPS-100 and the computer was powered by the remaining PPS-50. Ball's portable power fuel cell systems are designed to be load following and respond to the power demand instantaneously using a custom software control algorithm. The fuel cell systems tracked changes in power demand fast enough to avoid any brownout conditions for the radios. Two idling nets draw 25 W, one idle net and one transmitting net draw 40 W, and both nets transmitting draw 55 W. The entire retransmission site system used 30 W when idle and 130 W when transmitting.

Fuel cell setup in the back of the Humvee



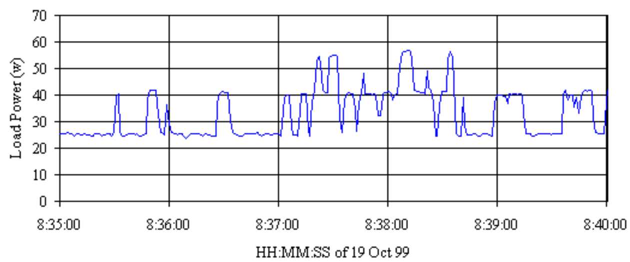
The hilltop site for retrans 2. The distant hill behind the antennas is OP Creole. The radios and fuel cell systems are in the Humvee.

The training that the Marines received during the test exercise and the CAX 1-00 allowed them to setup, operate, and assess the fuel cell power system and fuel source during CAX 2-00 without any assistance from Ball or CECOM. This was due to the capability of the Marines operating the system and the ease of operation of the fuel cell power system and its associated hydrogen system.

The final CAX of 1999, CAX 2-00, also produced positive results. Setup was accomplished in good time and the PRC-119 radios were operating properly. During the second exercise, one PPS-50 shut down due to a stack temperature failure. The portable power systems are designed to protect themselves from permanent failure by shutting off the load for some out-of-specification conditions and aborting in others. The PPS unit that shut down is currently being evaluated by Ball to determine the exact cause of the problem. Maj. Griggs stated that "the impact of the downed PPS-50 on the retransmission site was small. . . . They [the Marines operating the network] had redundancy to cover a much greater outage and were able to restore the working capability based upon brief training with you [Ball] and kept the six nets up throughout." Maj. Grigg's final report to the military showed that use of the fuel cell power systems rather than batteries resulted in a savings of $8,000 for one CAX operation alone.

Fuel Cells Summary

The total capacity of the fuel cell power systems used in the three exercises was 200 W nominal and 260 W peak or burst power. The test exercises did not truly stretch the limits of these systems using only 130 W of the total capacity at peak transmission. However, CAX 1-00 did demonstrate the suitability of the fuel cell system for load cycling operations and the practicality of using hydrogen. While the radio network was idle or inactive, only 25 W of power was required, which could have been supplied by only one PPS-50.



One-second samples of load power logged from PPS-50, SN#006. Two nets were attached to this supply. The low values of 25 W occur when both nets are idle. The 40 W power draw occurs when one of the nets is retransmitting and the 55 W power draw occurs when both nets are retransmitting.

At 100% duty cycle for one of the PPS-50 units, 55 W were required, which resulted from both nets transmitting simultaneously. The fuel cell power systems are able to respond in real-time to the load. The highest or peak load was planned to occur during the second application where the portable power systems were used to power a pre-amplifier system. When all nets and the Humvee radio are retransmitting, there is a combined power demand of 240 W on the three fuel cell power systems.

Hydrogen Usage and Operating Costs

The hydrogen usage and operating costs for the retransmission site demonstration and the two combined arms exercise activities was enlightening. The tables demonstrate that operating fuel cells is a cost-effective and efficient means of providing power.

Elements of Hydrogen Usage	Sum	Average	Units
Number of radios	---	9	
Number of power amps	---	0.25	
Number of notebook computers	---	0.25	
Running time	182.5	---	hr
Total energy produced	15353	---	Whr
Mean power to electrical loads	---	92.26244875	W
H_2 used	455.7	---	ft3
Energy produced / fuel used	---	37.94814273	Whr / ft3
Actual K bottles used	2.5535	---	
Activated carbon filters used	1	---	

The most significant data in the table are the total running time, total power, the amount of fuel used, and the total cost for each of the activities. Comparing the total power output by the fuel cells with the equivalent in battery provided power means that for an energy requirement of 15,353 Whr, 103 BA5590 batteries would have been required. These 103 batteries would cost $7,725 as compared to the total operating cost of $245.50 for the fuel cell power systems. After the initial fuel cell purchase, operating costs are less than 5% of the costs to operate BA5590 batteries (assuming the cost of a BA5590 battery is $75 / battery and provides 150 Whr of energy). On a per day basis, the table at the bottom of this page illustrates the cost comparison.

Maj. Griggs stated that a typical retransmission site uses 12 to 20 radios and each radio uses about one BA5590 per day of operation. The table at the top of the page 4 compares fuel cells and BA5590s to operate a 12-radio retransmit site with PRC-119 radios.

Maj. Griggs, Ssgt. Muzzall, Cpl. Clark and Cpl. Garcia said the system exceeded all expectations. There was initially some concern about working around the hydrogen bottles. It was a new type of fuel and the 1st Marines S-6 were not familiar with the robust nature of approved steel cylinders. After the initial training and use of the fuel cell system, Cpl. Clark and Cpl. Garcia were very comfortable working with the hydrogen gas fuel. Hydrogen is a mobile gas that rises and dissipates rapidly, compared to liquid fuels such as propane, gasoline and diesel fuels that collect in low areas and dissipate more slowly.

Special acknowledgements and thank you to Charlie Kiers and Jim Broyles for helping to arrange Ball's participation at these exercises, and to the 1st Marines, especially to Col. Paxton, Maj. Griggs, Cpl. Garcia and Cpl. Clark. Also, thanks to OST, ARL, SOCOM, DARPA, Army CECOM, ARO and I-MEF. The PPS fuel cell power systems are near their present state of development because of the dedicated support of these groups. ◇

Actual Operating Fuel Costs	Each	Subtotal	Units
No. of bottles	5		
No. of days bottles in field	49		
Bottle delivery and pickup	$4.00	$ 4.00	per trip
Fuel cost	$20.50	$102.50	per bottle
Bottle rental	$0.20	$49.00	per bottle-day
Activated carbon filter	$90.00	$90.00	
Sales tax		$11.74	
Total Cost		**$ 245.50**	
Total energy produced		15353	Whr
Cost per energy		$0.0160	$/Whr

Fuel Cell Cost per day of Operation		BA5590 Cost per day of Operation	
6 transmitting radios = 8 amps at 12 V (measured) 6 receiving radios = 3.5 amps at 12 V (measured) Energy used per day by 6 retransmit nets = 3.3 kWh per day			
Industrial grade H_2 gas ($20 / k bottle)	$7.50	12 BA5590 batteries per day ($75 each)	$900
k bottle rental ($6/month)	$0.20		
k bottle delivery ($8 for 5 k bottles)	$1.60		
Activated carbon H_2 filter ($45/ k bottle)	$16.88		
Total Cost per day	**$26.18**	**Total Cost per day**	**$900**

Thank You

Ball wishes to thank its customers, sponsors and partners for their support in helping to develop the fuel cell portable power systems. Special acknowledgements and thank you to Charlie Kiers and Jim Broyles for helping to arrange Ball's participation at the Marines Combined Arms Exercises, and to the 1st Marines, especially to Col. Paxton, Maj. Griggs, Cpl. Garcia and Cpl. Clark for their participation. Also thanks to OST, ARL, SOCOM, DARPA, Army CECOM, ARO and I-MEF. The fuel cell PPSs would not be near their present state of development without the dedicated support of these groups. ◇

New PPS Website!

Ball Aerospace & Technologies Corp. has been in the fuel cell power systems business for almost a decade. The first product created that began the technology development for Ball's fuel cell portable power systems was known as SNORKLER. The initial website created for that product has now been revamped to provide information on our latest products, the PPS-100 and PPS-50. These systems are small and lightweight, and will serve power requirements for applications up to 125 W, soon to be 500 W. Please visit us at http://www.ball.com/aerospace/cryfc.html, our new website, and fill out an inquiry form if you have an application that requires portable, reliable power from a durable system. ◇

Frequently Asked Questions

Here are answers to questions that have been asked by users of Ball's fuel cell portable power systems concerning hydrogen. Special acknowledgements to Air Products.

Is the 4.16 amperes the maximum amperage that the PPS-50 will produce?

The PPS-50 will supply 5 A at 12-13 V continuously, and 6.5 A at 11-12 V in bursts of several minutes.

Will the 50 W system shut down if it has a current draw that exceeds 4.16 amperes?

The PPS-50 will shut down if the current exceeds 7 A. The problem can then be corrected and the unit restarted using the on/off switch, or by pressing restart within 30 seconds of the abort (once the problem is corrected).

Temperature limits exist that will cause the fuel cell to either cycle the load or abort. If the fuel cell stack temperature reaches 70 °C, the load will be turned off and the cooling fan will operate until the stack temperature is less than 65 °C. Power will then be restored to the load.

If the stack temperature reaches 75 °C, the system will abort.

At 4.16 amperes of continuous current draw, what is the maximum time the unit will run?

The PPS-50 will supply 5 A continuously with ambient air temperature less than 40 °C. The run time is dependent upon the fuel source and the power draw.

What is the advantage(s) of using Ball's portable power fuel cell system over existing BA5590 lithium batteries as a power source?

During the Camp Pendleton Marine Corps. demonstration, $246 of hydrogen was consumed providing 15.4 kWh of energy as compared to $7,796 worth of BA5590 batteries to provide the same energy.

Weight savings for extended mission lifetimes are also of note.

Will the hydrogen (psi content) determine the run time of the system? Meaning if the bottle can only be charged to 3000 psi versus 4500 psi, how will that affect the running time or current output?

The hydrogen pressure in the storage bottle does determine how long the PPS-50 will produce electricity.

Kevlar composite bottle that has a 4" diameter and is 19" long; supplied as an option for a hydrogen fuel source.

PPS-50 Run Time with 4" dia. x 19" tall H_2 Bottle				
Bottle PSI at T= 21 °C (70 °F)	**Energy (Whr) to Load @ 50 W**	**Run time at 50 W**	**Minimum Run time at 20 W**	**Minimum Run time at 10 W**
4500	700	14.0	37.5	75.0
2000	311	6.2	16.7	33.3
1000	156	3.12	8.3	16.6
100	16.0	0.32	0.8	1.6
4	0.0	0.0	0.0	0.0

Industry standard steel bottle, k bottle that has a 9" diameter and is 48" tall.

PPS-50 Run Time with 9" dia. x 48" tall H_2 Bottle				
Bottle PSI at T= 21 °C (70 °F)	Energy (Whr) to Load	Run time at 50 W	at 20 W	Run time at 10 W
2000	7385.2	147.7	369.3	738.5
1000	3685.2	73.7	184.3	368.5
100	355.2	7.1	17.8	35.5
4	0.0	0.0	0.0	0.0

If the 4,500 psi capacity bottle is only filled to 3,000 psi, the resulting running time is only 2/3 of the potential.

The following tables demonstrate how long the PPS-50 system will run using two different types of hydrogen storage bottles under certain conditions.

Can the PPS-50 unit operate below 32 °F?

Yes, the PPS-50 can operate down to 0 °F. Internal heaters allow it to keep itself warm, however, it must be running for the temperature control system to operate.

The PPS-50 operating manual states the tank life cycles as >100 (fill cycles). What exactly does this mean? Would that need to be strictly monitored?

The DOT requires that compressed gas storage bottles (tanks) be hydrostatically certified every few years. This is the same regulation used for SCUBA and other tanks.

The certification period and contacts are provided with each hydrogen fuel source bottle that Ball provides.

The “>100 cycles” refers to an older version bottle that was rated for 10,000 psi and 100 pressure cycles between certifications that was used for the SNORKLER product.

How stable is the hydrogen and fuel cell durability for everyday use, air delivery, manpack configurations, etc.?

Two PPS-50s and one PPS-100 were transported and operated in the back of a Humvee for two months by the 1st Marines at the 29 Palms Marine base in the California dessert. Two of the 9" dia. x 50" (k bottle) tall hydrogen bottles were strapped in the back of the same vehicle. The hydrogen bottles and fuel cells were found to be quite durable.

The PPS units are shock rated and tested to survive a 3-foot drop onto concrete.

The hydrogen gas is a flammable material and cannot be transported on a passenger aircraft. Transport on cargo aircraft is allowed at the discretion of the pilot. When Ball takes the composite bottles on aircraft, they are first purged of hydrogen with nitrogen and then vented to atmospheric pressure.

What is the availability of hydrogen in foreign countries, and is it under strict control?

Hydrogen is available in many foreign countries through suppliers that also operate within the United States. U.S. suppliers work with foreign distributors to supply many gases, including hydrogen, throughout the world.

There are areas in which hydrogen or other gases may be more difficult to obtain, such as Eastern Europe including Russia and the Middle East. For these areas, one solution may be a portable hydrogen generator that can be plugged into an electrical outlet.

Ball’s low-pressure chemical hydrogen fuel cell source currently under development may solve these issues by allowing the hydrogen to be transported with the fuel cell.

The control of hydrogen in foreign countries is typically less stringent than that in the United States, but specifics for each country of interest would have to be obtained.

Is the hydrogen tank coupler a universal coupler for worldwide use, or would a bottle have to be supplied that can use a universal coupler?

The Compressed Gas Association (CGA) recommends specific fittings for specific gases in the United States.

The CGA 350 on a high-pressure cylinder is the adopted fitting for hydrogen (0.825" thread size; 14 external left-hand threads per inch)

Other countries have adopted their own standards and hydrogen gas suppliers must comply with the hardware requirements in the country of use.

Can Ball provide specific handling and storing procedures for hydrogen?

Additional information is provided in the PPS-50A Operator’s Manual.

Some items of note:

- Hydrogen gas is odorless and nontoxic, but may produce suffocation by diluting the concentration of oxygen in air, thus producing asphyxiation.
- The amount of hydrogen gas necessary to produce oxygen deficient atmospheres is within the flammable range.
- Eliminate sources of ignition such as sparks from electrical equipment, static electricity sparks, open flames, or any hot object in excess of 900 °F.
- Hydrogen readily migrates through small openings.
- Hydrogen burns with an almost invisible flame.

What are the hazardous cargo restrictions for transporting the hydrogen bottles on both civilian and military aircraft?

In Ball's experience on Marine Corps. helicopters, the decision to carry pressurized gases is up to the pilot. Pilots also make the decision on commercial cargo aircraft.

The storage bottles can be transported empty on passenger aircraft, but they must be purged with nitrogen or helium and then vented to atmospheric pressure. Ball's Safety Officer produces a letter for the airline stating that safety procedures have been undertaken and the storage bottles and fuel cell system do not present any hazard for passengers or the aircraft.

What training if any would be needed to handle bottles of hydrogen?

Ball can provide any necessary training. Training on filling and purging the hydrogen fuel tanks does not take long. ◇

Acronyms

DMFC	Direct Methanol (MeOH) Fuel Cell
MeOH	Methanol (methyl alcohol)
FC	Fuel Cell
I-MEF	I Marine Expeditionary Force
PEM	Proton Exchange Membrane or Polymer Electrolyte Membrane
PPS	Portable Power System or Personal Power System (usually in reference to an H_2 PEM system)

Events

The 11th Annual U.S. Hydrogen Meeting of the National Hydrogen Association, 29 February – 2 March 2000, Vienna, VA USA

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